

Distinguishing between MSSM and NMSSM with $e\gamma$ Scattering [★]

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Abstract

We study the associated production of selectrons and neutralinos with subsequent leptonic decay of the selectron in $e\gamma$ scattering within the framework of MSSM and NMSSM. Due to the weak couplings of singlino dominated neutralinos, associated neutralino production $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ at a linear collider can be strongly suppressed in some regions of the parameter space. Then the process $e\gamma \rightarrow \tilde{e}_{L/R} \tilde{\chi}_{1/2}^0 \rightarrow e \tilde{\chi}_{1/2}^0 \tilde{\chi}_1^0$ can give additional informations on the underlying theory and the character of $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$.

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1 Introduction

Supersymmetry is up to now one of the most attractive theories beyond the Standardmodel (SM). But from the theoretical point of view there exist many ways for a supersymmetric extension of the SM. One of the widely used models is the Minimal Supersymmetric Standard Model (MSSM) that has minimal content in the Higgs sector. The masses, mixings and couplings of the four neutralinos are determined by the parameters M_1 , M_2 , μ and $\tan\beta$. The minimal extension of the MSSM by a higgs singlet field S is the Next-to-Minimal

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Supersymmetric Standard Model (NMSSM) [1]. The neutralino sector now contains five neutralinos being mixtures of the MSSM gauginos and higgsinos and an additional singlino \tilde{S} . The NMSSM neutralino mixing depends on the parameters M_1 , M_2 , $\tan\beta$, the singlet vacuum expectation value x and the trilinear couplings λ and κ [2]. For large values of x the singlino dominated neutralino decouples and the remaining four neutralinos have the same masses and characters as in the MSSM if one identifies $\mu = \lambda x$ [5].

The linear collider (LC) will first run in the e^+e^- -mode. However, associated neutralino production $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ may not give sufficient evidence for a discrimination between MSSM and NMSSM, especially if this is the only kinematical accesible neutralino production process in the e^+e^- -mode. In our contribution we want to investigate the possibilities to distinguish between the models with the help of $e\gamma$ scattering $e\gamma \rightarrow \tilde{e}_{L/R} \tilde{\chi}_{1/2}^0 \rightarrow e \tilde{\chi}_{1/2}^0 \tilde{\chi}_1^0$.

2 Cross sections of $e\gamma \rightarrow \tilde{e}_{L/R} \tilde{\chi}_1^0 \rightarrow e \tilde{\chi}_1^0 \tilde{\chi}_1^0$

We first study the associated production of left/right selectrons and the lightest neutralino (LSP) in $e\gamma$ scattering. The high energetic photon comes from Compton back-scattering of laser photons off one electron beam at a LC. The production proceeds via s-channel exchange of an electron and t-channel exchange of selectrons. The formulas for special cases are given in [3], the complete analytical expressions for the differential and total cross sections for polarized beams will be given in a forthcoming paper [4]. The subsequent decay of the selectrons in electrons and the LSP leads to an e^- and missing energy in the final state. The total cross section for the production and decay in the ee -cms depends on the polarisation P_e of the electron beam, the helicity λ_L of the laser photon and the helicity λ_e of the converted electron beam.

In fig. 1 we show the contours of constant total cross sections for the process $e^- \gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_{L/R} \rightarrow e^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$ in the M_2 - μ -plane for the MSSM and the M_2 - x -plane for the NMSSM for $\sqrt{s_{ee}} = 500$ GeV. For the calculations we choose the longitudinal polarisation of the electron beam $P_e = 80\%$, the helicity of the converted electron beam $\lambda_e = -80\%$ and the helicity of the laser photon $\lambda_L = 100\%$. This set of polarisations can be achieved at TESLA and leads to the most significant contours. We set $\tan\beta = 3$, the common scalar mass $m_0 = 110$ GeV and use the GUT relation $M_1 = 5/3 \tan^2 \theta_W M_2$. The trilinear couplings are choosen as $\lambda = 0.5$ and $\kappa = 0.1$ (fig. 1b), $\lambda = 0.5$ and $\kappa = 0.01$ (fig. 1c) and $\lambda = 0.1$ and $\kappa = 0.01$ (fig. 1d).

If in the NMSSM the $\tilde{\chi}_1^0$ is dominated by the singlino content the production is supressed, because electron and selectron only couple to the gaugino components of the neutralino. Then the total cross section is smaller than 1 fb in

some parameter regions (fig. 1b-d) and probably lies below the detection limit of a $e\gamma$ collider. Otherwise one obtains cross sections similar to the MSSM. For $M_2 > 0$ there also exist a small band with $1 \text{ fb} < \sigma < 10 \text{ fb}$ (fig. 1c/d). In this region the $\tilde{\chi}_1^0$ is the mainly singlino-like, but nevertheless it will be very difficult to extract this small signal from the background $e\gamma \rightarrow W\nu$ [6].

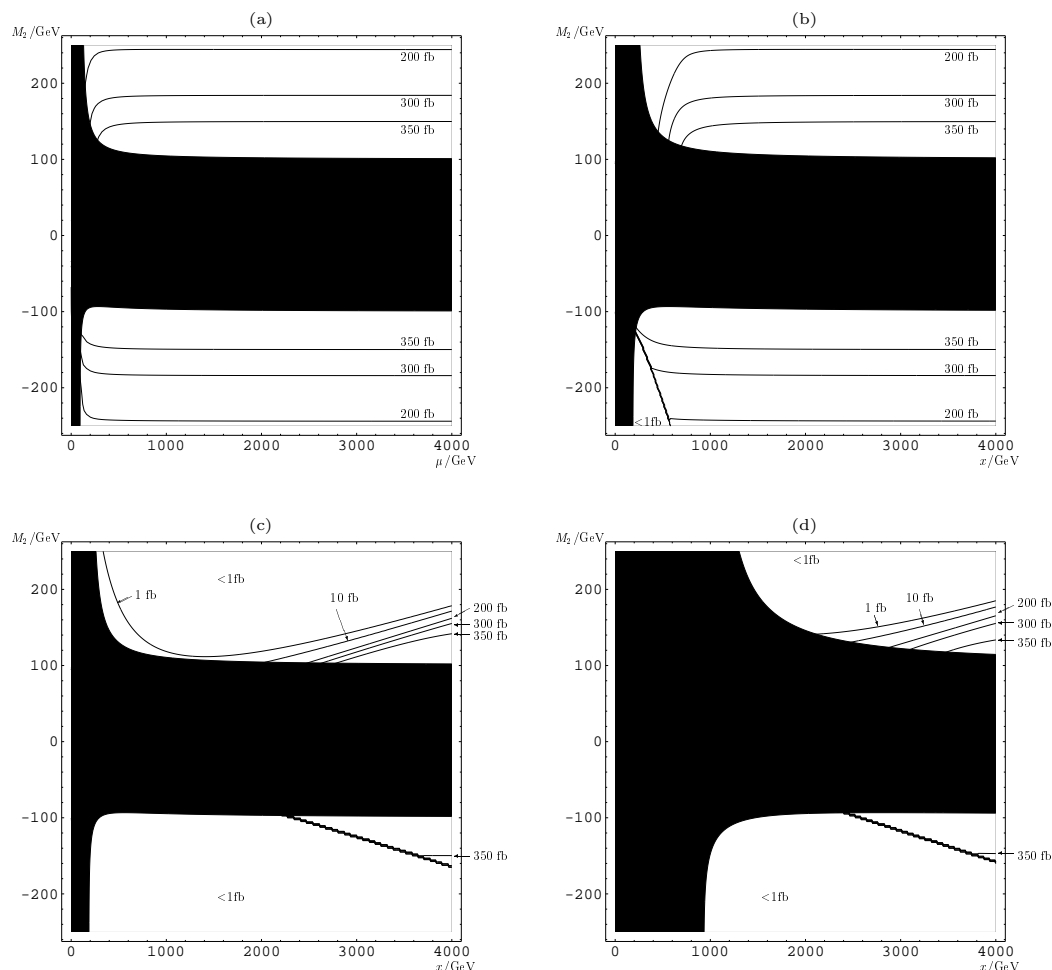


Fig. 1. Contours of constant total cross sections for the process $e^-\gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_{L/R} \rightarrow e^-\tilde{\chi}_1^0 \tilde{\chi}_1^0$ for $\sqrt{s_{ee}} = 500 \text{ GeV}$, polarisations $P_e = 80\%$ of the electron beam, $\lambda_e = 80\%$ of the converted electron beam, $\lambda_L = 100\%$ of the laser photon and the parameters $\tan\beta = 3$, $m_0 = 110 \text{ GeV}$: (a) MSSM; (b) NMSSM with $\lambda = 0.5$ and $\kappa = 0.1$; (c) NMSSM with $\lambda = 0.5$ and $\kappa = 0.01$; (d) NMSSM with $\lambda = 0.1$ and $\kappa = 0.01$.

3 Distinguishing NMSSM and MSSM with $e\gamma$ Scattering

In this section we consider two cases: (a) $\tilde{\chi}_1^0$ has singlino character and $\tilde{\chi}_2^{0,NMSSM}$ corresponds to $\tilde{\chi}_1^{0,MSSM}$; (b) $\tilde{\chi}_2^0$ is singlino dominated and $\tilde{\chi}_1^0$ is similar in NMSSM and MSSM. In table 1 we present four reference scenarios I, II (a)

	Scenario I	Scenario II	Scenario III	Scenario IV
M_2/GeV	520.	-513.9	353.0	-346.3
x/GeV	1600.			
λ	0.5			
κ	0.0531	0.05295	0.0794	0.07923
$m_{\tilde{\chi}_1^0}/\text{GeV}$	(-)173.4	(-)173.4	(-)173.4	(+)173.4
$m_{\tilde{\chi}_2^0}/\text{GeV}$	(-)256.6	(+)256.6	(-)256.6	(-)256.6
$m_{\tilde{\chi}_3^0}/\text{GeV}$	(-)504.3	(+)513.5	(-)343.8	(+)348.1
$\langle \tilde{S} \tilde{\chi}_1^0 \rangle^2$	0.98	0.99	0.0024	0.0008
$\langle \tilde{S} \tilde{\chi}_2^0 \rangle^2$	0.0027	0.0009	0.979	0.99

Table 1

Reference scenarios with fixed $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$ (signs of the mass eigenvalues in brackets). In scenario I and II the $\tilde{\chi}_1^0$ is mainly singlino and in scenario III and IV $\tilde{\chi}_2^0$ is singlino-like.

and III, IV (b) with fixed $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$ for comparison. In all scenarios the lightest MSSM-like neutralino is dominated by gaugino components, which couple to electrons and selectrons, while the higgsino components do not. For $m_{\tilde{\chi}_2^0} > \sqrt{s_{ee}}/2$ and $m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_3^0} > \sqrt{s_{ee}}$, the only channel for direct production of neutralinos in e^+e^- annihilation is $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$. However, if one of the neutralinos is mainly singlino this process will be suppressed. The cross sections for the process $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ in fig. 2a are calculated with longitudinal polarisations $P_{e^-} = 80\%$ of the electron beam and $P_{e^+} = -60\%$ of the positron beam. Fig. 2b/c shows the cross sections for $e^-\gamma \rightarrow \tilde{\chi}_{1/2}^0 \tilde{e}_R \rightarrow e^- \tilde{\chi}_{1/2}^0 \tilde{\chi}_1^0$ with polarisations $P_e = 80\%$, $\lambda_e = -80\%$ and $\lambda_L = 100\%$ in the reference scenarios. In all scenarios we fix the masses $m_{\tilde{e}_R} = 180$ GeV and $m_{\tilde{e}_L} = 300$ GeV.

3.1 If $\tilde{\chi}_1^0$ is singlino-like...

... we expect for $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ a production cross section of $\sigma = 0.9$ fb for scenario I and $\sigma = 0.27$ fb for scenario II at $\sqrt{s_{ee}} = 500$ GeV (fig. 2a). The smaller cross section in scenario II is due to the different relative signs of $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\chi}_2^0}$, which leads to cancellations in the interference terms [7]. Now it will be a question of luminosity and background suppression, whether the cross sections are measurable. Even if a signal is detected, the decision whether $\tilde{\chi}_1^0$ or $\tilde{\chi}_2^0$ is the singlino dominated neutralino will be difficult since the cross sections are very similar ($\sigma = 0.9$ fb in scenario I and $\sigma = 1.1$ fb in scenario III, see

fig. 2a). In $e\gamma$ scattering the process $e^-\gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_1^0 \tilde{\chi}_1^0$ will be strongly suppressed (see sec. 1). Then the first detectable neutralino production process at a high luminosity collider will be $e^-\gamma \rightarrow \tilde{\chi}_2^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_2^0 \tilde{\chi}_1^0$. Fig. 2c shows total cross sections of $\sigma = 3.8$ fb in scenarios I and II at $\sqrt{s_{ee}} = 500$ GeV which further increase for higher energies. This process, however, will lead to a completely different final state compared to the LSP-selectron production because of the additional decay of the $\tilde{\chi}_2^0$ [7]. Therefore one can decide via detection of the $e\gamma$ process that the $\tilde{\chi}_1^0$ is mainly singlino.

If the e^+e^- cross section is too small for detection, the production and decay of $\tilde{\chi}_2^0$ together with \tilde{e}_R in $e\gamma$ will be the first direct production process of neutralinos that would be measurable at $\sqrt{s_{ee}} = 500$ GeV with high luminosity. The non-detection of the $\tilde{\chi}_1^0 \tilde{e}_R$ production suggests a singlino-like $\tilde{\chi}_1^0$ and therefore extended supersymmetry as the underlying theory.

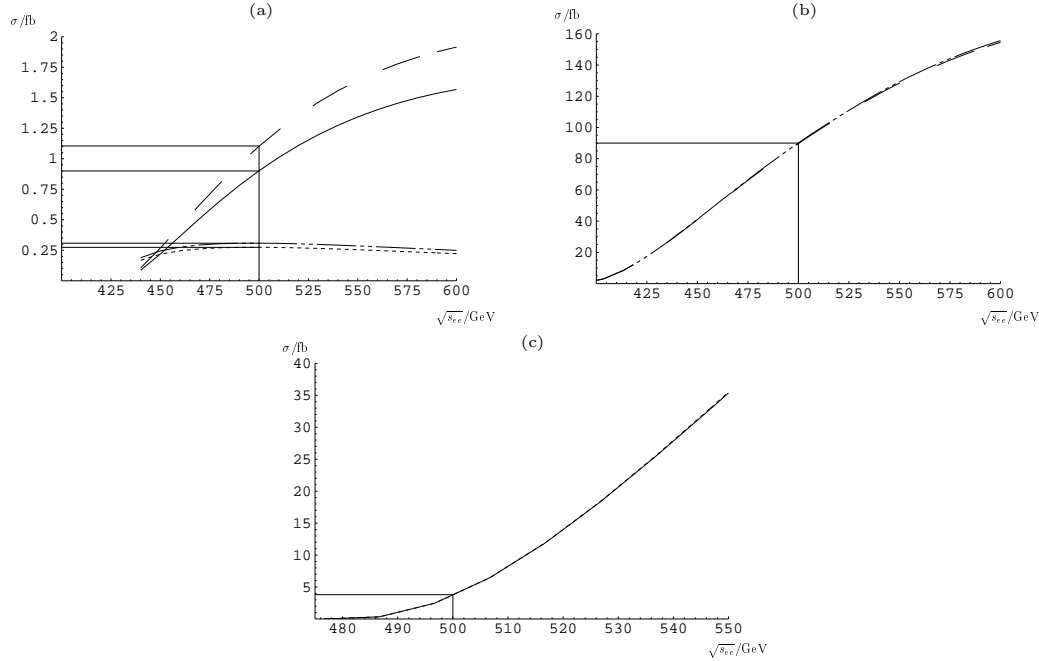


Fig. 2. Total cross sections in scenario I (full line), scenario II (dotted line), scenario III (dashed line) and scenario IV (dashed-dotted line): (a) $\sigma(e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0)$ with longitudinal polarisation $P_{e^-} = 80\%$ and $P_{e^+} = -60\%$; (b) $\sigma(e^-\gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_1^0 \tilde{\chi}_1^0)$ with polarisations $P_e = 80\%$, $\lambda_e = -80\%$, $\lambda_L = 100\%$; (c) $\sigma(e^-\gamma \rightarrow \tilde{\chi}_2^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_2^0 \tilde{\chi}_1^0)$ with same polarisations as in (b).

3.2 If $\tilde{\chi}_2^0$ is singlino-like ...

... we expect for $e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ a production cross section $\sigma = 1.1$ fb in scenario III and $\sigma = 0.31$ fb in scenario IV at $\sqrt{s_{ee}} = 500$ GeV. If one assumes these cross section to be detectable one again can use $e\gamma$ scattering to decide which

neutralino is singlino dominated. The detection of the process $e^-\gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_1^0 \tilde{\chi}_1^0$ would prove the singlino character of $\tilde{\chi}_2^0$. In scenario III and IV one obtains $\sigma = 90$ fb for $\sqrt{s_{ee}} = 500$ GeV (fig. 2b).

If, however, the cross section for associated neutralino production in e^+e^- annihilation can not be observed, the process $e^-\gamma \rightarrow \tilde{\chi}_1^0 \tilde{e}_R \rightarrow e^-\tilde{\chi}_1^0 \tilde{\chi}_1^0$ would be the first process for direct production of neutralinos. But this process alone does not allow to discriminate between the MSSM and the NMSSM.

4 Conclusion

- For a singlino dominated $\tilde{\chi}_1^0$ the associated production of selectrons and the LSP in $e\gamma$ -scattering will be strongly suppressed.
- $e\gamma \rightarrow \tilde{\chi}_{1/2}^0 \tilde{e}_{L/R}$ could be the first process to identify neutralinos and to determine the underlying supersymmetric model.
- If neutralino pair production $e^-e^+ \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ gives evidence for a neutralino with singlino character, the $e\gamma$ process can be used to decide, whether $\tilde{\chi}_1^0$ or $\tilde{\chi}_2^0$ is singlino dominated.

References

- [1] J. Ellis, J.F. Gunion, H.E. Haber, L. Roszkowski, F. Zwirner, *Phys. Rev.* **D 39** (1989) 844;
M. Drees, *Int. J. of Mod. Phys.* **A 4** (1989) 3635;
T. Elliot, S.F. King, and P.L. White, *Phys. Lett.* **B 314** (1993) 56; *Phys. Rev.* **D 49** (1994) 2435;
U. Ellwanger, M. Rausch de Traubenberg, and C.A. Savoy, *Phys. Lett.* **B 315** (1993) 331;
B.R. Kim, A. Stephan, and S.K. Oh, *Phys. Lett.* **B 336** (1994) 200;
F. Franke and H. Fraas, *Int. J. Mod. Phys.* **A12** (1997) 479.
- [2] F. Franke, H. Fraas and A. Bartl, *Phys. Lett.* **B336** (1994) 415;
U. Ellwanger and C. Hugonie, *Eur. Phys. J. C5* (1998) 723; *Eur. Phys. J. C13* (2000) 681.
- [3] J. A. Grifols, R. Pascual, *Phys. Lett.* **B135** (1984) 319.
F. Cuypers, G. J. van Oldenborgh, R. Rückl, *Nucl. Phys.* **B383** (1992) 45.
F. Cuypers, G. J. van Oldenborgh, R. Rückl, MPI-Ph/93-70, LMU-93/12.
- [4] C. Blöchinger, H. Fraas, in preparation.
- [5] S. Hesselbach, F. Franke, and H. Fraas, WUE-ITP-2000-008, hep-ph/0003272, contribution to the Proceedings of the *2nd Joint ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider*.

- [6] M. Baillargeon, G. Bélanger, F. Boudjema, ENSLAPP-A-473/94.
- [7] F. Franke and H. Fraas, Z. Phys. **C 72** (1996) 309.